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A Model of Shield-Strata Interaction and Its Implications for Active Shield Setting Requirements

By Thomas M. Barczak and David C. Oyler

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	psi	pound per square inch
in	inch	psi/c	pound per square inch per cycle
kip/in	kip per inch	psig	pound per square inch, gauge
min	minute	psi/min	pound per square inch per minute
pct	percent		

SYMBOLS USED IN THIS REPORT

A	area	K_{S1}, K_{S2}	stiffness of individual shields
d	distance	L	length
D	shield displacement	NA	neutral axis of composite beam
E	modulus of elasticity	p, r	reaction distances
F	main roof loading	P	resultant suppport resistance
F_A	active setting load	R	reaction force to maintain moment of equilibrium
F_P	passive load	w	distributed load
F_T	total shield load	W	weight
h_1	thickness of immediate roof	X	average setting pressure
I	moment of inertia	δ	beam deflection
K	stiffness		
K_{C1}, K_{C2}	elements of coal		

A MODEL OF SHIELD-STRATA INTERACTION AND ITS IMPLICATIONS FOR ACTIVE SHIELD SETTING REQUIREMENTS

By Thomas M. Barczak[1] and David C. Oyler[2]

ABSTRACT

This U.S. Bureau of Mines study evaluates factors that influence longwall support and strata interaction. The longwall system is composed of an immediate and main roof structure and three supporting foundations: longwall panel, powered roof supports, and gob waste. The main roof forms a structure that is generally supported by all three foundations, while the immediate roof acts as a beam that cantilevers from the coal face to the powered support. In most cases, shield loading involves a complex interaction of both main roof and immediate roof behavior and is a combination of loads produced from convergence of the main roof and displacements of the immediate roof caused by deformations of the cantilevered roof beam. Since the shield stiffness remains constant for all leg pressures and main roof convergence is irresistible in terms of shield capacity, the shield must be able to control the behavior of the immediate roof or floor structure for shield loading to be sensitive to setting pressures. If the goal is to minimize total shield loading, any active setting force must be offset by reduced passive shield loading to justify the active setting loads. Field data suggest that the typical reductions in passive loading do not justify the required increases in setting pressure in some applications.

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INTRODUCTION

Two primary goals of the U.S. Bureau of Mines in researching underground coal mining are to reduce the cost of mining coal and to ensure the health and safety of the miner. This study seeks to help achieve these goals by formulating a model to improve selection and employment of roof supports to maintain adequate ground control.

The tremendous potential of longwall mining can be realized only if adequate ground control is maintained. Hence, powered roof support specifications are critical to longwall mining. Two primary considerations in shield selection and employment are (1) shield capacity, which is measured in terms of the yield pressure of the hydraulic leg components, and (2) setting pressure, which is used to actively set the shield against the roof at the beginning of the shield cycle. Despite the importance of the powered roof support system, the interaction of the supports with the strata is not well understood, as evidenced by a wide variety of support applications under similar mining conditions (*1*).[3]

Shield capacities continue to increase for all applications (fig. 1). This increase in shield capacity has been obtained by employing larger sized (area) hydraulic components while keeping the hydraulic yield pressure constant at approximately 6,500 psi. Setting forces have also increased in direct proportion to the increase in yield capacities as the hydraulic setting pressures have remained constant at about 4,000 psi. Furthermore, setting pressures are arbitrarily selected without consideration of geological conditions. Current and past practice has been to set shields at 50 to 60 pct of yield capacity for all conditions.

These trends indicate that further research is needed to provide a better understanding of strata behavior and associated shield response to provide for better shield selection and employment. A goal is to match the utilization of shield capacity to the conditions in which shields are employed. Since total shield loading is largely developed from the initial setting force, optimum utilization of the available shield capacity requires the selection of an optimum setting force that minimizes total shield loading while maintaining the stability of the immediate face area. Shield resistance above that needed to maintain ground control unnecessarily stresses the support structure and surrounding strata, which may reduce shield life and degrade roof stability. Hence, optimum shield selection and utilization can improve safety and productivity through better ground control and reduce maintenance expenditures for the shield supports.

Several theories of longwall support and strata interaction have been developed through the years. Until recently, the inability to collect high-quality in situ shield load measurements has limited verification and development of these concepts. State-of-the-art electrohydraulic control systems and permissible data acquisition systems now provide unprecedented data, in both quantity and quality, to facilitate the development of improved longwall support and strata interaction models.

Historically, longwall support and strata interaction has been modeled as a detached roof block that must be maintained in equilibrium by the powered support resistance as illustrated in figure 2 (*2*). The premise of this concept is force-controlled roof behavior where face convergence is controlled by the shield resistance, suggesting a strong correlation of shield load development to setting pressures. The detached block concept ignores main roof convergence, which is irresistible in terms of the shield capacity.

More recently, longwall support and strata interaction models have considered the equivalent stiffness of the total ground-supporting system (longwall panel, shields, and the gob) as illustrated in figure 3 (*3-4*). This concept promotes displacement-controlled roof behavior and adequately describes face convergence and subsequent shield loading in response to main roof activity, but tends to ignore the local behavior of the immediate roof, which may be dependent on shield resistance.

The purpose of this report is to incorporate the salient features of these and other concepts to develop a model of longwall support and strata interaction that better describes observations of in situ shield response. The model considers shield load development from both the main roof and immediate roof structure. The main roof structure is the portion of the overlying rock mass that maintains sufficient structural integrity to maintain stability such that it does not produce localized loading in the immediate face area. The weight of the main roof is

[3]Italic numbers in parentheses refer to items in the list of references at the end of this report.

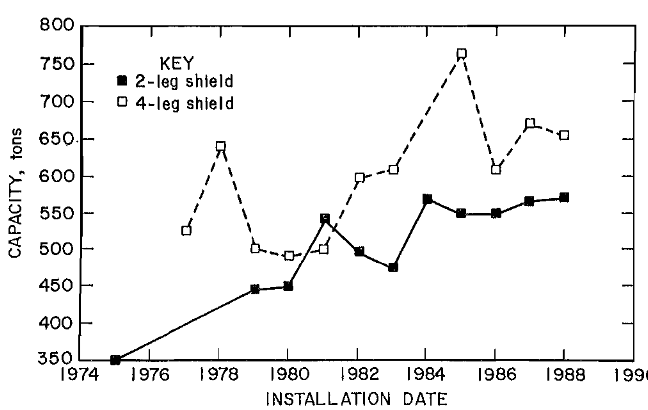

Figure 1.—Historical trend in shield capacities.

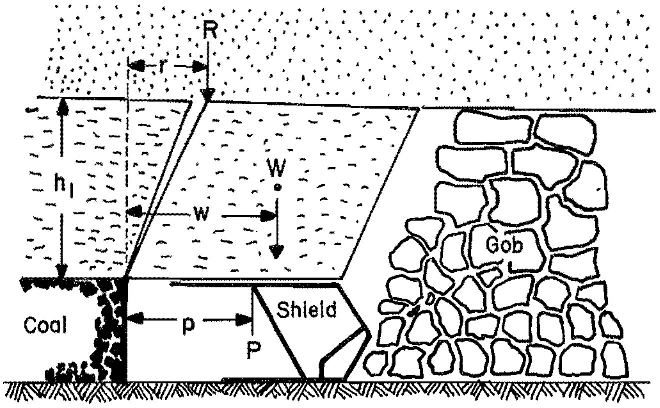

Figure 2.—Detached block model of longwall support and strata interaction. Equilibrium requirements: force equilibrium: W + R = P; moment equilibrium: W(w) + R(r) = P(p). [Adapted from Wilson as discussed in reference 2.]

widely distributed among the overall ground-supporting foundations, being carried by the in situ coal within the panel and the gob waste some distance from the immediate face. As the coal is extracted, the overlying rock mass is known to subside (converge). Hence, while the main roof weight is not directly felt by the powered supports, its downward displacement through subsidence is a source of roof-to-floor face convergence and shield loading. The immediate roof is modeled as a beam of variable bending stiffness that cantilevers from the yield zone in the coal face to or beyond the powered support. Shield loading is described as a combination of loads produced from (1) convergence of the main roof in proportion to the stiffness of the ground-supporting system and (2) displacements of the immediate roof controlled by the weight and bending stiffness of the cantilevered roof beam and by the resistance developed by the shields.

The concept proposed in this report is based on limited underground data. Longwall support and strata interaction is a complex behavior of several mechanisms. A primary goal of this report is to stimulate thinking on this controversial issue. While the concept proposed here appears to explain observations of in situ shield responses, insufficient research has been done to verify the mechanisms on which this concept is formulated. Any application of the results reported here should consider these limitations.

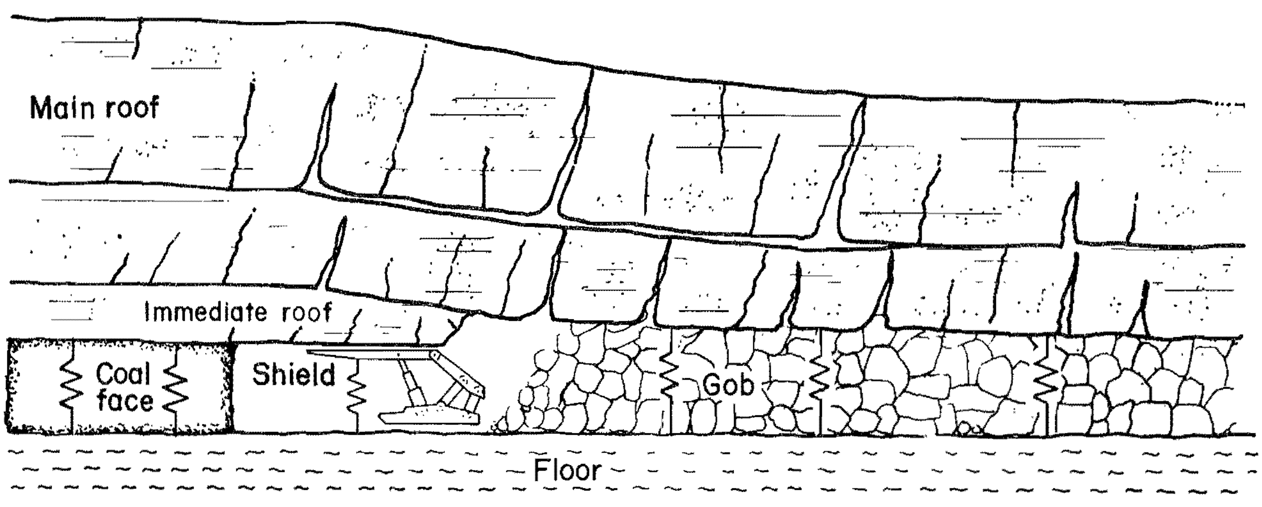

Figure 3.—Equivalent system stiffness model of longwall support and strata interaction.

IN SITU SHIELD LOADING OBSERVATIONS

Bureau and other researchers have monitored shield leg pressures on a number of longwall faces during the past decade. From these data, shield response during a mining cycle and correlations of data parameters, such as total shield loading, change in loading after being set against the roof, loading rate after setting, and active setting pressure, have been derived. The data presented in this report are from an eastern Kentucky longwall that employs 780-ton two-leg longwall shields. The geology is characterized as a thin shale immediate roof overlaid by a relatively thick sandstone. The lithology is shown in more detail in figure 4. These data were selected primarily because of the high quality of the data and not the site geology. From the perspective of shield response, this site is similar to other observed longwall faces.

LOADING PROFILES

A typical profile of shield leg pressure development during a mining cycle is shown in figure 5. The shield is initially loaded by actively setting it against the roof by external pressurization of the hydraulic leg cylinders. Once the shield is set against the roof, hydraulic fluid is trapped in the leg cylinder and the shield becomes a passive support. Subsequent loads are developed in response to vertical and horizontal displacements of the canopy relative to the base in proportion to the stiffness of the support structure. Hence, total shield loading, as indicated in equation 1, is the sum of the initial load, created by actively setting the shield, plus the subsequent passive load, developed in response to roof convergence.

$$F_T = F_A + F_P, \tag{1}$$

where F_T = total shield load,

F_A = active setting load,

F_P = passive load,

$F_P = K_{SHIELD} \cdot D$,

K_{SHIELD} = shield stiffness,

and D = shield displacement.

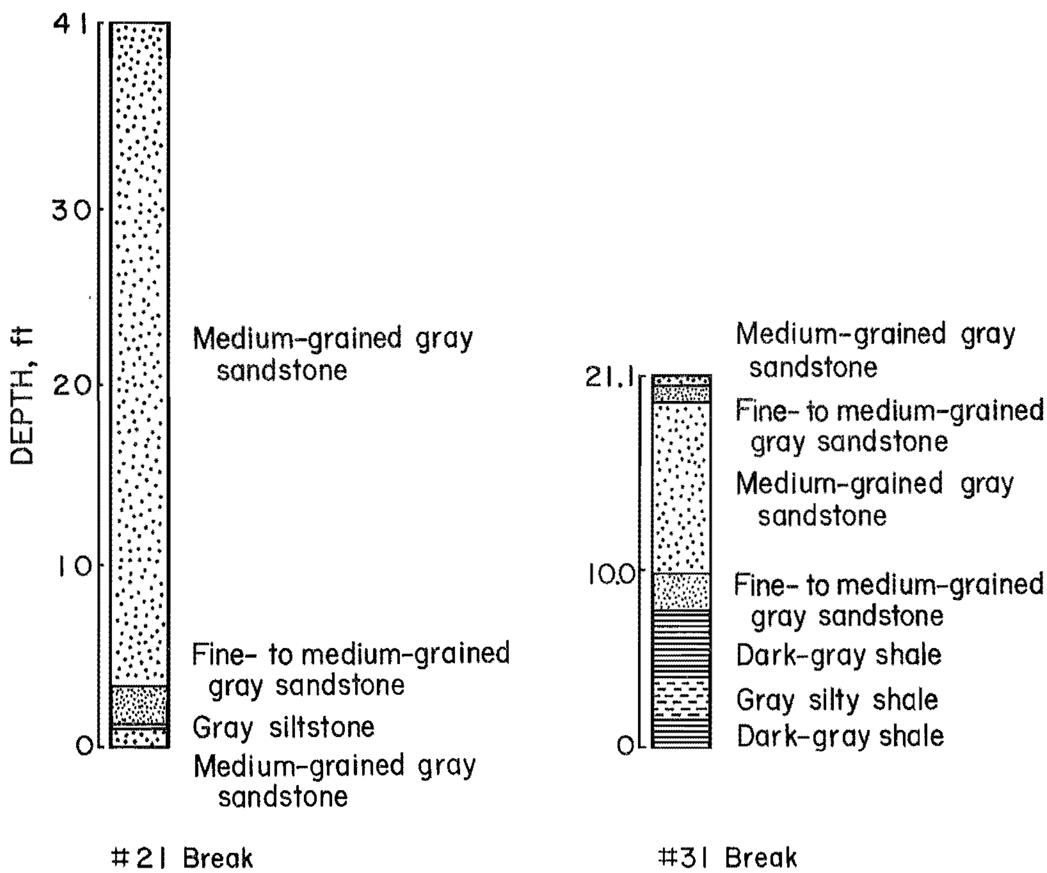

Figure 4.—Stratigraphic column of roof strata at eastern Kentucky longwall at break 21 and break 31.

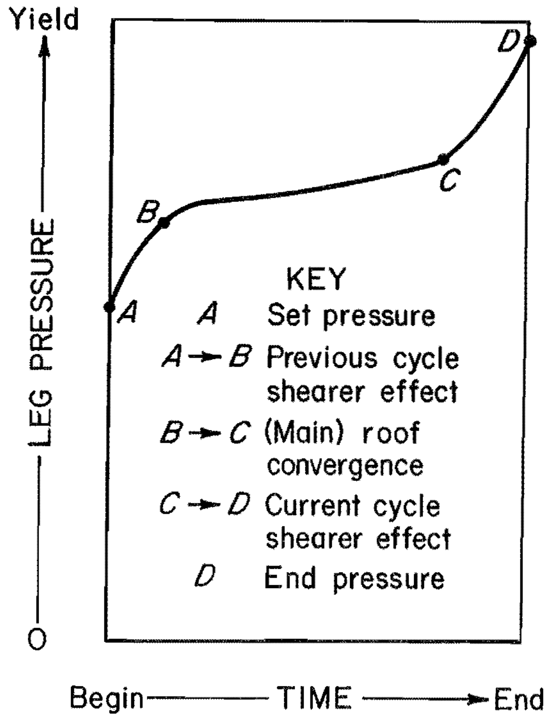

Figure 5.—Typical shield cycle showing leg pressure development.

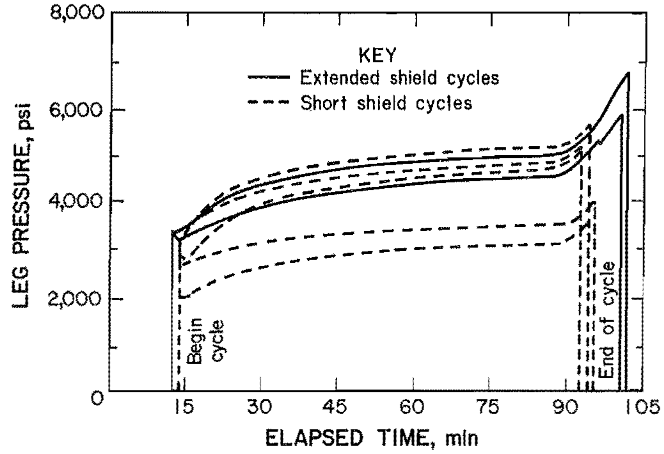

Figure 6.—Effect of shearer extraction at end of mining cycle.

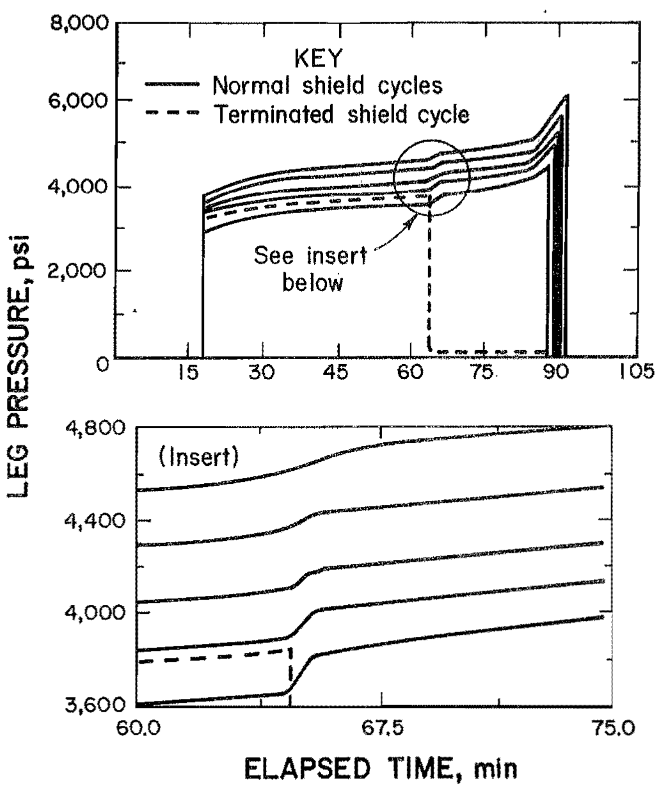

Figure 7.—Effect of adjacent shield advance on shield loading.

Shield loading rates vary during the mining cycle in response to mining activities that affect roof behavior. Maximum loading rates are generated in response to the shearer extraction of face coal in the immediate vicinity of the shield. The shearer effect is seen toward the end of the shield cycle (period C to D in figure 5) in higher rates of roof convergence several tens of feet in front of the approaching shearer, and the effect is present after the shearer passes the shield. Typically the shield is lowered before the shearer effect ends, so the shearer effect is also seen after the support is advanced and reset against the roof at the beginning of the next cycle. Evidence to support this claim is shown in figure 6, which shows that two shields lowered several minutes later than adjacent shields maintained the same load rate well after the adjacent shields were advanced.

Also included at the beginning and end of the cycle are the effects of the advancement of adjacent shields. The change in shield loading produced from the adjacent shield advance is typically an order of magnitude below that of the shearer effect, as illustrated in figure 7, where one shield among the six monitored was lowered near the middle of the mining cycle and not reset for the remainder of the cycle.

During the middle portion of the cycle when the shearer is some distance past the shield (estimated at 125 to 150 ft for the Kentucky longwall), the shearer effect at the beginning of the cycle disappears and a substantially reduced loading rate is observed (period B to C in figure 5). This loading rate is fairly constant, which indicates a constant rate of convergence. This is also the lowest loading rate observed during the shield cycle.

DATA CORRELATIONS

Figure 8 depicts the correlation of passive shield loading, defined as the difference between the leg pressure when the shield is set against the roof (setting pressure) and the final leg pressure when the shield is lowered, as a function of setting pressure for 138 mining cycles representing 1 full week of mining. To avoid localized effects of individual shield performance in situations where a shield may not be fully participating in providing roof control, an average change in shield loading on 11 consecutive shields was computed. Each data point on the graph represents one mining cycle averaged over these 11 shields. Similar behavior was observed for single shield responses.

A weak correlation of passive shield loading to different setting pressures was observed. This might be attributed to changes in strata geology or inconsistencies in the duration of the mining cycle. However, the envelope of the data (maximum change in loading corresponding to a given set pressure) suggests some setting pressure dependency. It appears that passive shield loading increased with increasing setting pressures up to approximately 3,200 psi, and then decreased with increasing setting pressures for setting pressures above 3,200 psi. Since passive shield load development is produced in response to displacement, the observed behavior requires increasing displacements for increased setting pressures up to 3,200 psi and reducing displacements for increased setting pressures beyond 3,200 psi. A similar relationship was observed for shield loading rate, computed as the change in shield loading after the shield is set divided by the time required to produce this change in loading.

SUPPORT AND STRATA INTERACTION MECHANICS

The model proposed in this paper is illustrated in figure 9. As indicated in the introduction, the main roof structure is supported by the coal panel, the powered supports, and the gob waste, and the immediate roof is considered as a beam that cantilevers from the coal face to the powered supports. Shield loading in relation to strata mechanics largely depends on whether the immediate roof remains coupled to the main roof. At one extreme, the immediate roof forms a free block that must be maintained in equilibrium solely by the powered support resistance (fig. 2). At the other extreme, there is no well-defined immediate roof or the immediate roof remains coupled to the main roof and shield loading is governed by the behavior of the main roof (fig. 3). In most cases, shield loading involves a complex interaction of both main roof and immediate roof behavior and is a combination of loads produced from convergence of the main roof and displacements of the immediate roof caused by deformations of the cantilevered roof beam. A detailed analysis of these mechanisms follows.

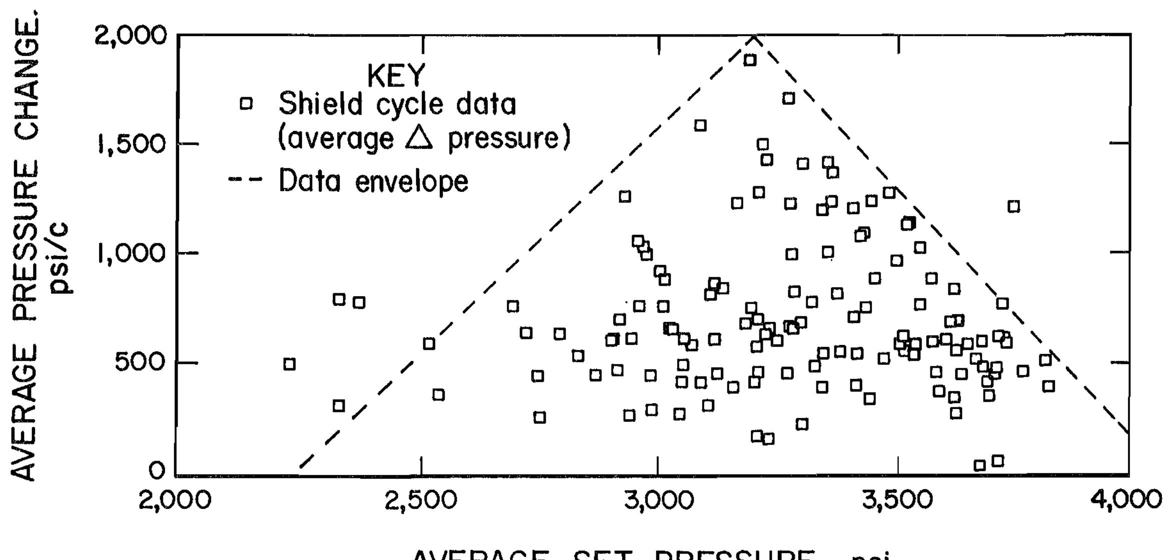

Figure 8.—Correlation of passive shield loading to active setting pressure.

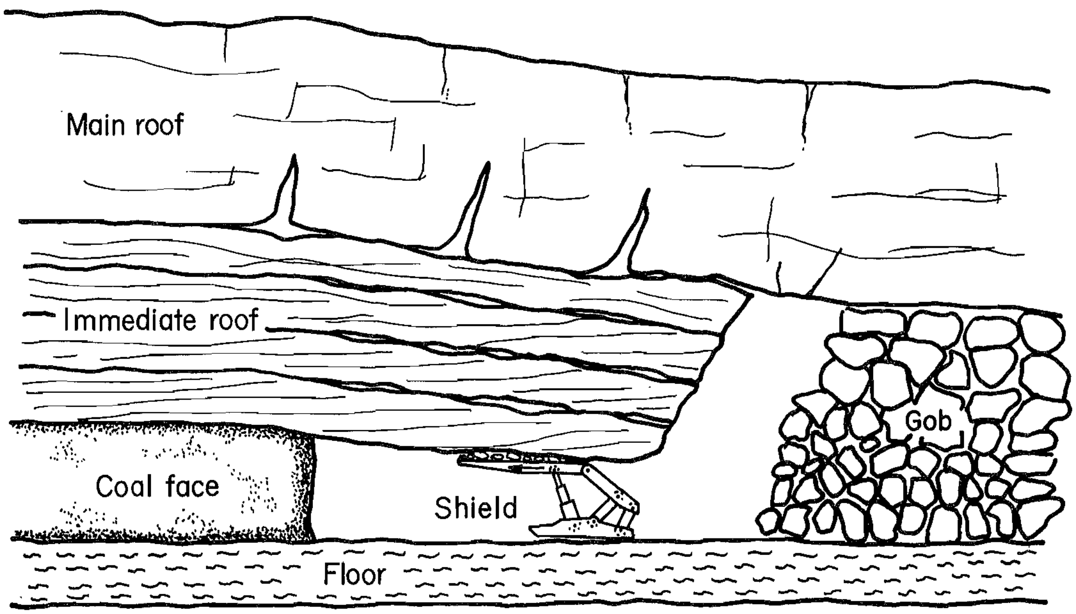

Figure 9.—Proposed model of longwall support and strata interaction.

COUPLED MAIN ROOF AND IMMEDIATE ROOF BEHAVIOR

When the immediate roof remains coupled to the main roof, support and strata behavior is best described by analysis of the equivalent stiffness of the ground-supporting system. The underlying principle of a model based on stiffness is that the forces developed in the supporting elements are a function of the applied displacements to the supports and the stiffness of the supports as expressed in equation 2.

$$F_{SYSTEM} = [\, K_{SYSTEM} \,] \cdot D_{SYSTEM}, \qquad (2)$$

where F_{SYSTEM} = roof and floor loading,

K_{SYSTEM} = system stiffness,

and D_{SYSTEM} = roof-to-floor convergence.

In the context of underground coal mining, forces are imposed on the supporting system in response to the displacement of the overlying rock mass as the coal seam is extracted. Displacement equates to roof-to-floor convergence. In a static situation, the roof force is equilibrated by the force resistance of the supporting system. In a dynamic situation in which equilibrium is not attained, the forces and displacements are replaced by first derivatives producing force rate and displacement rate, which relate to rates of loading of the supporting system.

The face coal, powered supports, and gob form a system of parallel supports, as illustrated in figure 3, with mechanical springs to simulate the stiffness of the ground-supporting elements. The equivalent stiffness of this system is the sum of the coal, powered support, and gob stiffness as described in equation 3.

$$K_{SYSTEM} = K_{COAL} + K_{POWERED\ SUPPORT} + K_{GOB}, \qquad (3)$$

where K_{COAL} = coal stiffness,

$K_{POWERED\ SUPPORT}$ = powered support stiffness,

and K_{GOB} = gob stiffness.

In reality, the face is three-dimensional, and additional supporting elements could be added to simulate the full face, but for purposes of discussion a two-dimensional representation, as shown in figure 10, will be used.

Assuming a constant roof and floor load, face convergence is a function of the stiffness of the total ground-supporting system. Roof convergence and associated load development in the support elements will be at a minimum when the system stiffness of the supporting elements is at a maximum. Load distribution among the individual support elements is determined by their relative stiffnesses. Since the shield stiffness is constant for all leg pressures (5), load development in the shield should not be dependent on shield setting pressures. Hence, total shield loading will be minimized when setting loads are minimized, suggesting that passive shield application where the shield is set in contact with the roof without applying any active force provides optimum employment to minimize shield loading.

A more detailed examination (fig. 10) indicates that the shield acts in series with the immediate roof and floor strata, producing an equivalent stiffness as described in equation 4.

$$K_{\text{POWERED SUPPORT SYSTEM}} = \frac{1}{\frac{1}{K_{\text{ROOF}}} + \frac{1}{K_{\text{SHIELD}}} + \frac{1}{K_{\text{FLOOR}}}}. \quad (4)$$

where $K_{\text{POWERED SUPPORT SYSTEM}}$ = powered support system stiffness,

K_{ROOF} = roof stiffness,

K_{SHIELD} = shield stiffness,

and K_{FLOOR} = floor stiffness.

Elements acting in series assume the general behavior of the least stiff element, and the equivalent system stiffness is always less than any one of the components. Therefore, only if the roof and floor stiffness approach infinity will the equivalent system stiffness equal that of the shield. Hence, the presence of an immediate roof or floor structure, which is also acted upon by the main roof loading (convergence), reduces the equivalent stiffness for the powered support system (roof, shield, and floor series). This reduction results in less shield loading (per unit displacement of main roof convergence) despite the shield stiffness remaining constant. In essence, a portion of the (main) roof convergence is consumed in the displacement of the immediate roof and/or floor structure and the full displacement does not go into the shield.

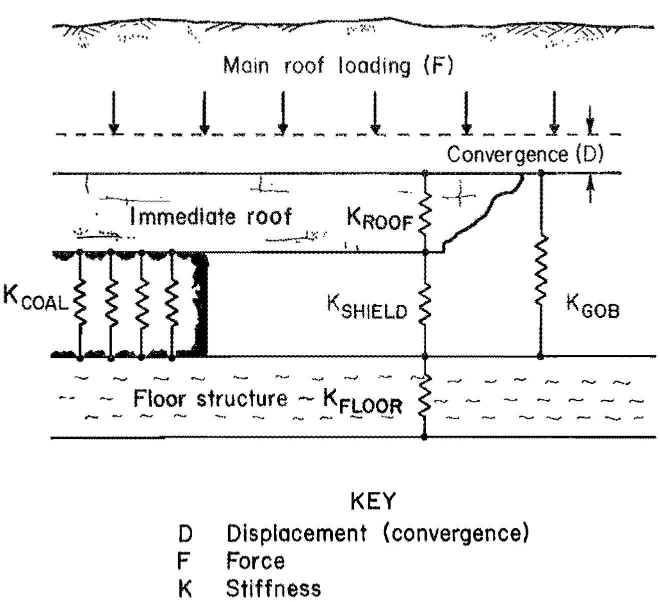

Figure 10.—Powered roof support interaction with immediate roof and floor strata.

If it is assumed that the stiffness of the roof or floor strata is force dependent, then it can be postulated that the equivalent stiffness of the powered roof support system can be modified by changes in shield forces as illustrated in figure 11. For example, if there is a layer of debris on the shield canopy, the stiffness of this debris may increase with compaction from increases in shield force. This increase in stiffness of the roof would produce higher shield loading since more of the roof convergence would be seen by the shield.

Referencing equation 2, any increase in the equivalent stiffness of the powered support system reduces face convergence for a constant roof load, suggesting that higher setting pressures may reduce face convergence and passive shield load development. However, it is necessary to consider the relative stiffness of the powered support system with that of the coal and gob structure to evaluate the effects of increased stiffness of the powered support system. The stiffness of the shield is known to be approximately 1,000 kip/in (5), which represents the maximum stiffness attainable for the powered support system (roof, shield, and floor series). A representative modulus of elasticity for coal is 250,000 psi. Computing the stiffness of the coal structure using the relationship $K = A \cdot E / L$ where A = area, E = modulus of elasticity, L = length, the coal structure stiffness is computed as 25,000 kip/in per unit shield width for a 6-ft seam (L = 6 ft) assuming a very modest 10 ft of coal supporting distance into the face (A = shield width · 10 ft). Since the coal structure stiffness is at least an order of magnitude greater than the powered support system, the powered support system stiffness represents only a very small portion of the overall ground-supporting system stiffness and therefore has very little effect in terms of controlling main roof convergence.

Therefore, increasing the axial stiffness of the immediate roof or floor by increasing shield setting pressures does not significantly reduce face convergence and associated passive shield load development. It is more likely that the increased stiffness of the immediate roof or floor transmits more of the roof convergence to the shield causing higher shield loading. Hence, passive shield application is recommended under these conditions to minimize shield loading.

Using the equivalent stiffness concept, changes in shield loading due to shearer extraction of the coal and adjacent shield advance are explained in terms of changes in stiffness of the ground-supporting system. Coal in the

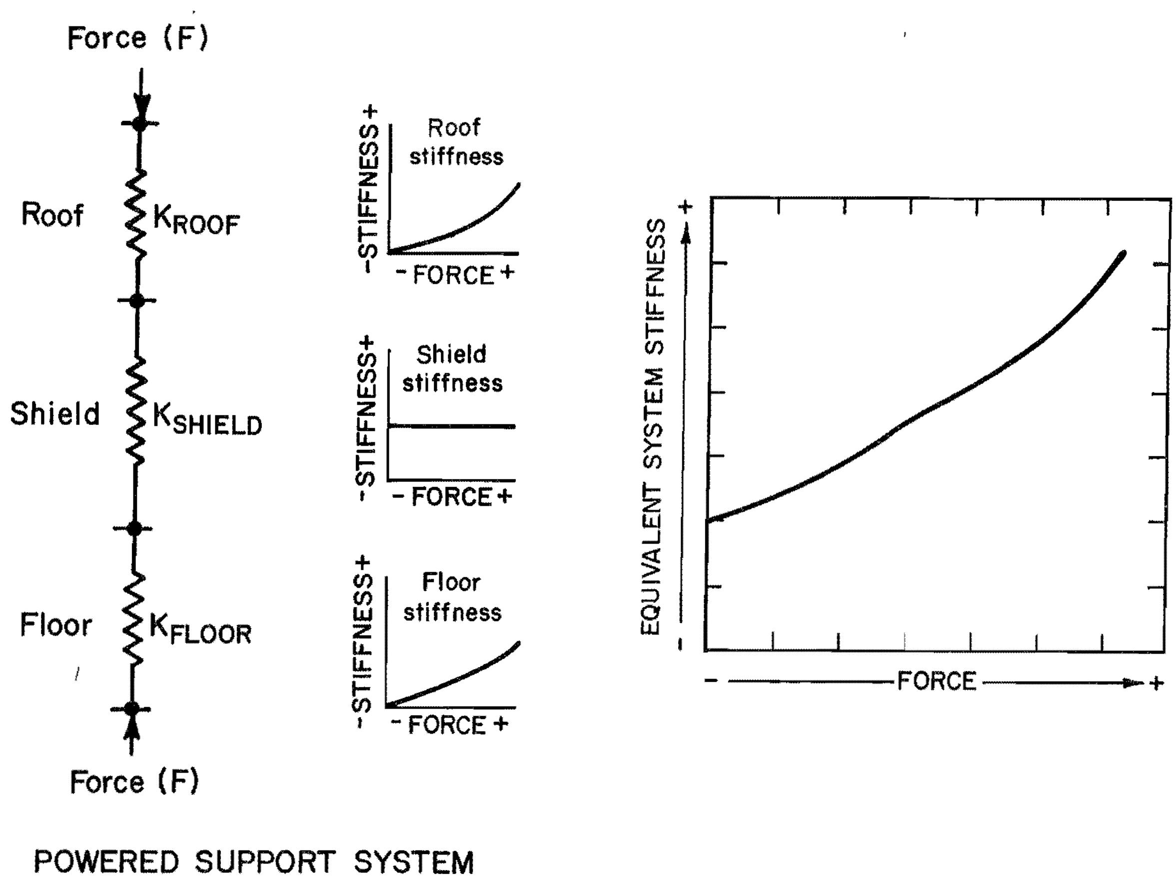

Figure 11.—Hypothetical force dependency of immediate roof and floor and associated equivalent stiffness of powered support system.

face area is modeled as several parallel elements as indicated in equation 5.

$$K_{COAL} = K_{C1} + K_{C2} + \ldots\ldots + K_{CN}, \tag{5}$$

where $K_{C1,\,C2,\ldots\,CN}$ = elements of coal.

Removing elements of coal then reduces the stiffness of the coal structure. The modulus of the coal in the immediate face area may also be reduced because of a loss of confinement from the face extraction, which would further reduce the stiffness of the coal structure in the immediate face area. The reduced coal structure stiffness causes an increase in roof convergence in the immediate face area, which produces load development in the shield in proportion to its stiffness.

Similar analyses may be applied to other face functions, such as adjacent shield advance, which is also known to increase shield loading rate. Shields along the face act as a system of parallel supports providing an equivalent system stiffness equal to the sum of the individual shields as indicated in equation 6.

$$K_{SHIELD} = K_{S1} + K_{S2} + \ldots\ldots + K_{SN}, \tag{6}$$

where $K_{S1,\,S2,\,\ldots\,SN}$ = stiffness of individual shields.

When adjacent shields are lowered, the system stiffness is reduced and additional loading is seen on neighboring shields from the increase in convergence.

However, the effect is very localized. Lowering one shield does very little to reduce the overall face stiffness; hence, load transfer is localized to shields in the immediate vicinity of the shield being advanced. Since the stiffness of the shields is substantially less than that of the coal, the increase in loading from shield advance is considerably less than that produced by the shearer extraction, which reduces the more dominant coal structure stiffness.

DETACHED IMMEDIATE ROOF BEHAVIOR

When the immediate roof becomes decoupled from the main roof, immediate roof displacements exceed main roof convergence, and shield load development is determined by the displacements of the immediate roof. As shown in figure 12, the roof beam deflects from loading produced by its weight in proportion to the bending stiffness of the beam. This deflection then causes a shield displacement and associated load development proportional to the shield stiffness. Since the shield stiffness remains constant for all leg pressures and if it is assumed that the deformation characteristics of the immediate roof do not change, passive shield loading is not dependent on the shield setting pressures and active setting is not required. Equilibrium of the strata is provided by passive shield resistance generated from displacement of the immediate roof.

Previously it was suggested that the axial stiffness of the immediate roof or floor may be increased by increasing setting pressures, but it was concluded that this would have minimal effect on controlling main roof convergence and most likely would increase shield loading by transmitting more of the main roof convergence to the shield. However, if increasing the setting pressure increases the structural moment of inertia of the immediate roof beam, its bending stiffness would increase as indicated in equation 7, and the corresponding shield loading from the beam deflection would be reduced.

$$K = (12 \cdot E \cdot I) / L^3 \tag{7}$$

where K = bending stiffness,

E = modulus of elasticity,

I = moment of inertia,

and L = beam length.

If the immediate strata consist of several bedded layers, then it can be postulated that the frictional forces between layers would increase with increased shield resistance, i.e., setting force, producing a composite beam with increased moment of inertia and beam stiffness. In essence, the moment of inertia of the composite beam is much greater than the sum of the moments of inertia of the individual layers of which the beam is composed (fig. 13). This composite beam behavior is similar to the generally accepted model of the effects of roof bolting, in which the bolt binds a number of weak laminated layers into a single beam with an increased bending resistance.

As illustrated in figure 5, shield loading rates are observed to increase as coal is extracted. The previous section described this increase in shield loading from reduction in coal structure stiffness and associated increase in main roof convergence. The increased shield loading can also be explained in terms of immediate roof behavior. Assuming the immediate roof acts as a cantilevered or simply supported beam, the bending stiffness is highly dependent on the beam length, as indicated in equation 7. Hence, as the beam length increases from removal of the face coal, its stiffness is reduced, causing larger deflections that produce additional shield loading. Cutting a 2-ft web could increase the deflection of a 15-ft roof cantilever by an additional 65 pct.

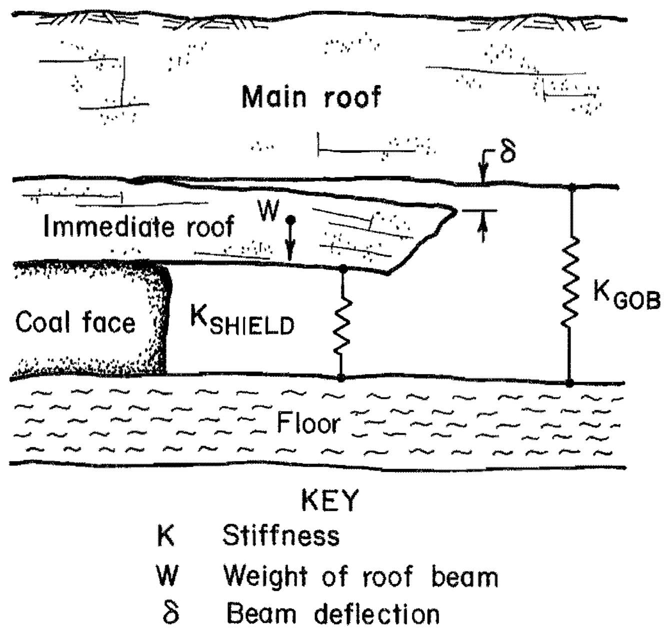

Figure 12.—Cantilevered beam deflections of immediate roof structure.

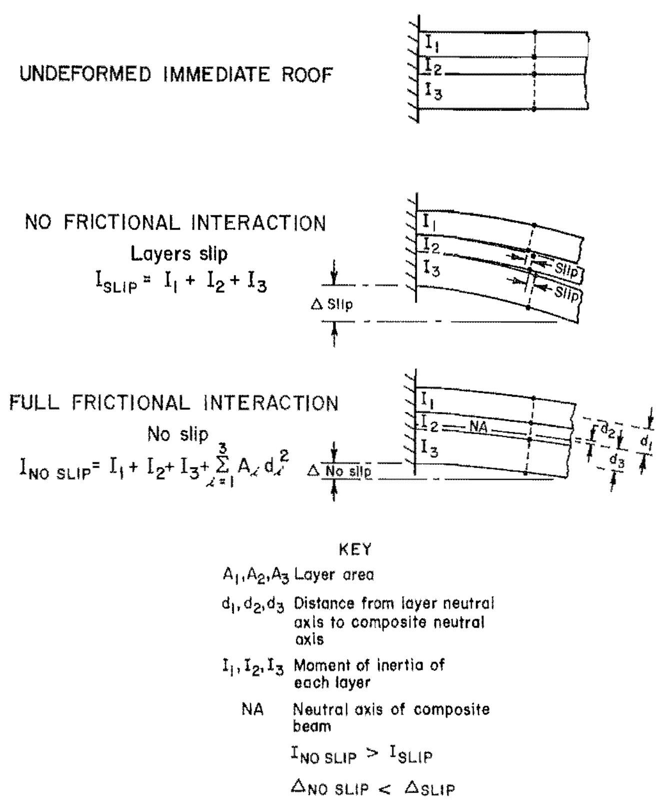

Figure 13.—Composite beam effects of immediate roof strata.

$$\delta = \frac{wL^4}{8EI} \quad (8)$$

where δ = beam deflection,

w = distributed load,

L = beam length,

E = modulus of elasticity,

and I = moment of inertia.

In the worst case, beam deflections under decoupled immediate roof conditions may be large enough to cause failure of roof strata at the coal face so that the immediate roof forms a free block that is solely supported by the shield. Another possibility is that bed separation of the immediate roof at the main roof boundary causes failure of upper members of the immediate roof, transferring additional loading (weight) onto the cantilevered immediate roof structure directly above the shield. An active setting pressure may improve these conditions provided the structural stiffness of the immediate roof beam is increased by the additional shield resistance.

INTERPRETATION OF MEASURED SHIELD LOADING

Changes in shield loading produced during the mining cycle in response to face extraction (fig. 5) are due to the combination of reduction in the axial stiffness of the coal structure and lengthening of the immediate roof beam. From the data available at the Kentucky minesite, it cannot be positively determined which is the more dominant factor. Examining the mathematics of the proposed mechanisms, the axial stiffness of the coal structure changes in direct proportion to the area (A) of the coal structure, $K = (A \cdot E) / L$, while the bending stiffness of the immediate roof beam is a function of the cube of the beam length (L), $K = (12 \cdot E \cdot I) / L^3$. This relationship indicates that the roof beam bending stiffness is more sensitive to changes in beam length than the axial coal structure stiffness is sensitive to changes in area. However, it does not conclusively indicate whether reduction in the axial stiffness of the coal structure or lengthening of the roof beam is the dominant factor, since they are different mechanisms.

A similar analysis can be applied to evaluate shield advancement. The fact that a change in load is seen from lowering a single shield (fig. 7) suggests that this behavior is due to local activity of the immediate roof, since lowering one shield would not significantly change the overall face stiffness (see equation 6).

Figure 14 indicates that shield load development during the middle portion of the cycle when the shearer is not in the vicinity of the shield (period B to C in figure 5) is insensitive to leg setting pressures. This insensitivity implies that this loading is developed from main roof convergence and that the immediate roof or floor structure stiffness remains constant during this period.

Since the shield stiffness remains constant for all leg pressures and main roof convergence is irresistible in terms of shield capacity, the shield must be able to change the stiffness of the immediate roof or floor for passive shield load development to be sensitive to setting pressures. From the previous analyses, it is clear that a model of longwall support and strata interaction must consider the effects of both axial and bending stiffness of the immediate roof and floor strata to evaluate shield load development and its sensitivity to active setting pressures. The model is complicated by the fact that increases in axial and bending strata stiffness produce opposite effects relative to passive shield load development. Hence, consideration must be given to the more dominant factor to determine optimum setting forces.

At the minesite from which the data were presented in figure 8, the axial stiffness effects (increase in material stiffness due to compaction) appear to dominate at low setting pressures (below 3,200 psi) while the bending stiffness effects (increase in bending stiffness of the immediate roof beam from interaction among strata layers forming a composite beam) appear to dominate at high setting pressures (above 3,200 psi).

Another explanation for the decrease in shield load development at the higher setting pressures is that the effective axial stiffness of the strata is reduced through crushing of the immediate roof or floor leading to a reduction in modulus of elasticity for the immediate roof or floor strata. In general, since the shield is not likely to produce strata loading at the strata-shield boundary in excess of 1,000 psi, which is well below the compressive strength of most coal measure strata, the shield is unlikely to induce sufficient force to fracture roof or floor material, except at contact asperities, which may produce some localized failure and reduce stiffness.

If the factor to be optimized is shield loading, optimum setting pressures can be determined by examining total shield loading as a function of setting pressure. For the data presented in figure 8, this relationship is illustrated in figure 15. The graph shows that minimum total shield loading was developed at the minimum set pressure, indicating that the benefits derived from reduced passive load development at the higher setting pressures are offset by the higher active setting loads (equation 1). This analysis suggests that for these conditions, passive shield application would produce the least overall shield loading.

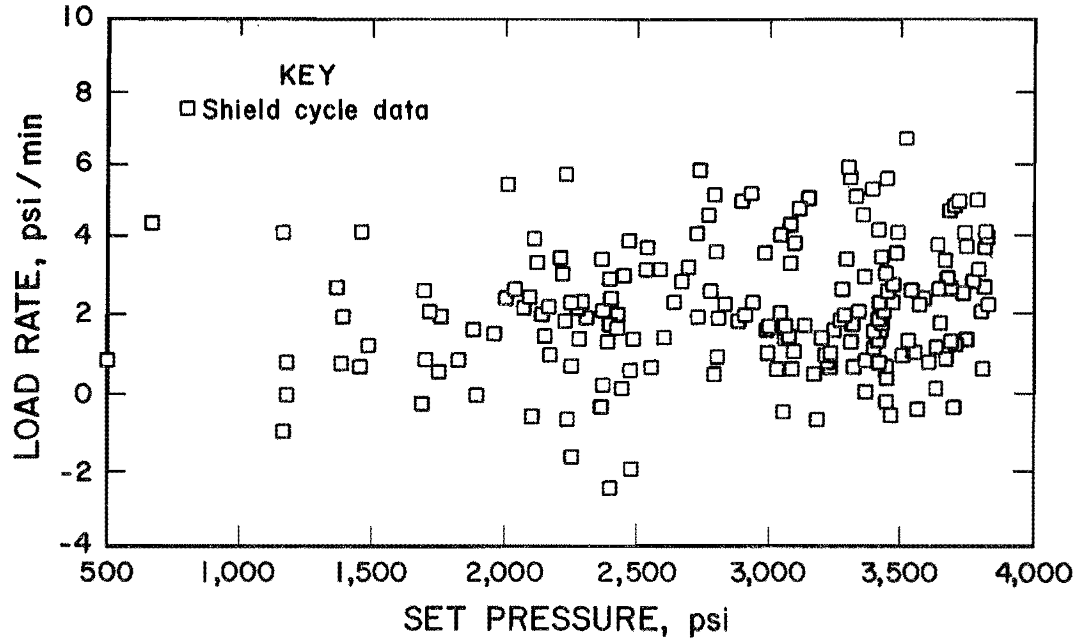

Figure 14.—Shield load development during main roof loading showing independence toward active setting pressure.

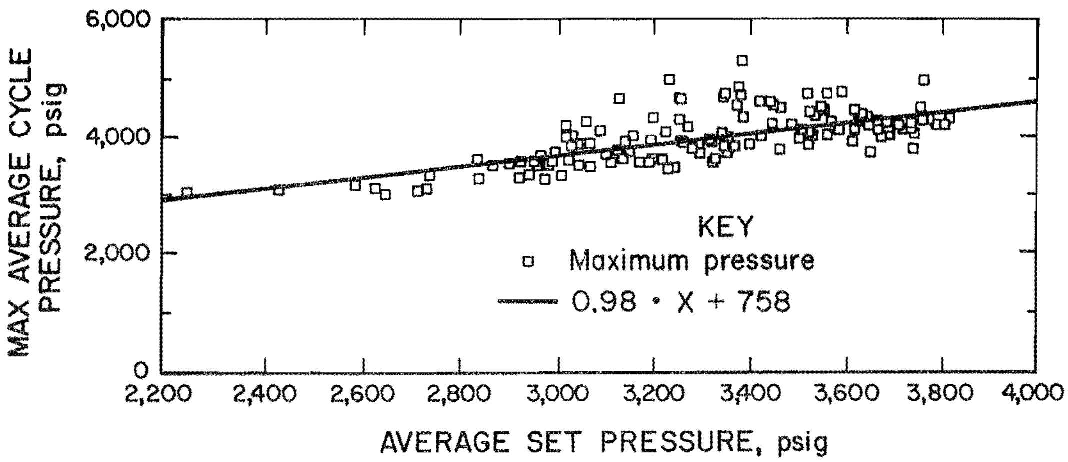

Figure 15.—Total shield loading as a function of active setting pressure.

SUMMARY AND CONCLUSIONS

Strata mechanics associated with longwall mining are a complex interaction of the main roof structure, the immediate roof and floor structure, and the ground-supporting elements, which are the coal panel, the powered roof supports, and the gob waste. Historical concepts of longwall support and strata interaction do not fit well with measured in situ shield loading. Other concepts need to be explored. The model proposed in this report is one such concept. Such models may lead to better definitions of support capacity and setting loads for various geological conditions. Optimum employment of shield capacity may increase shield life and improve ground control by minimizing unnecessary shield and strata loading.

Four points are made from the proposed model that are critical to shield capacity and active setting force considerations.

1. The primary function of the powered supports is to control the immediate roof, which cannot maintain stability without additional support. The shield has inadequate

capacity to significantly affect the behavior (convergence) of the main roof. Main roof behavior is primarily controlled by the stiffness of the coal structure in the face area and the stiffness of the gob waste in the region beyond the face.

2. Total shield loading is the sum of the initial load generated from active shield setting plus the load generated in response to strata convergence, which is described as the product of the convergence and the shield stiffness. Currently, setting loads represent the majority of overall shield loading, since the current practice is to set shields at 50 to 60 pct of the yield capacity. Any effort to minimize shield loading must consider both sources of loading.

3. A critical point in understanding shield load development is that the shield stiffness remains constant for all leg pressures. This means that the shield's ability to resist convergence is the same regardless of the setting pressure or overall shield resisting force. Therefore, for displacement-induced roof behavior in which force equilibrium of the strata is not attained or controlled by the shields, shield load development is independent of setting pressures.

4. It is postulated that increased shield resistance (setting force) can influence strata behavior in two ways: (1) by increasing the axial stiffness of the immediate roof or floor through compaction of broken debris or (2) by increasing the bending stiffness of the immediate roof beam by increasing the moment of inertia through frictional forces developed between individual strata layers. Shield loading would increase in response to the debris compaction and decrease in response to increased bending stiffness of the immediate strata.

In consideration of these four critical points, it is concluded that shield response and optimum employment depend on whether main roof or immediate roof behavior dominates. Passive application, in which the shield is set in contact with the roof without applying any force, is recommended for main roof behavior where the convergence is irresistible in terms of shield capacity. Minimizing the setting force would preserve more of the available shield capacity to accommodate the main roof convergence in these conditions. Immediate roof and floor strata are postulated to exhibit force dependency characteristics relative to their axial and bending stiffness. The ability to minimize total shield loading through active setting forces depends on the capability of the shield to increase the bending stiffness of the immediate strata enough to offset increased loading from increases in axial stiffness of the immediate strata and to offset the additional load caused by the higher setting loads. Data analyzed from one minesite in eastern Kentucky suggest reduced setting pressures would minimize total shield loading despite apparent reductions in passive shield load development at high setting pressures. Hence, there appears to be evidence for reduced setting pressures in some applications.

The justification for passive support application or reduced setting pressures as proposed in this report is based on the criteria to minimize overall shield loading. It is recognized that the reduced setting pressure may produce increased immediate strata convergence, and a decision must be made based on site-specific geological conditions if this increased convergence may cause roof stability problems. However, the stiffness of state-of-the-art shield supports permits about 1 in of displacement when used only as a passive support, and it is this magnitude of convergence that should be considered in these evaluations.

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